THEORY AND PRACTICE OF DATA ASSIMILATION IN OCEAN MODELING

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Award Number N00014-92-J-1595

LONG-TERM GOALS

The long range goal of this project is to combine computational models with observational data to form the best picture of the ocean as an evolving system, and use this picture to understand the physical influences which govern the ocean's behavior. Oceanic observations are sparse and models are limited in accuracy, but taken together, one can form a quantitative description of the state of the ocean that is superior to any based on either models or data alone. Along with the goal of analysis and prediction, we seek reliable estimates of the errors in our results. We expect our results to have implications beyond data assimilation. In particular we hope this research will lead to enhanced understanding of the implications of nonlinearity and randomness for predictability of the ocean and atmosphere.

Ultimately, formal theory of nonlinear filtering should be adapted for application to oceanic data assimilation, in order to find the best possible scheme for assimilating data into practical models of the real nonlinear ocean. The next generation of data assimilation techniques must be specifically designed for use with nonlinear models. It is our long range goal to develop these methods.

OBJECTIVES

The principal objective of this project is the development, implementation and validation of practical data assimilation methods for synoptic ocean models. By “data assimilation,” we mean the construction of a composite estimate of the state of the ocean based on a combination of observed data with computational model output. Since data assimilation methods which give the most and best information are highly resource intensive, and often not practical for operational use with detailed models, we are particularly interested in the price paid in terms of accuracy and confidence for using economical but suboptimal data assimilation methods.

Optimized methods require accurate knowledge of the statistics of the errors in the model and the data. It is therefore an objective to understand in detail the sensitivity of data assimilation schemes to the details of the defining error estimates.

APPROACH

The basic assumptions underlying data assimilation methods in use or proposed are known to be false to some degree. We plan to study the consequences of these assumptions by constructing a hierarchy of schemes with decreasing reliance on ad hoc assumptions. It is our guiding philosophy that the best way to learn how to design and implement the most economical methods that meet our needs is to begin by implementing methods which are as close to optimal as possible. From that point, we can quantify the loss of accuracy and the saving of resources associated with each simplification of the model or the data assimilation scheme.

Prior estimates of the model and data error statistics determine the relative weighting of the model output and the observations in the final product. Reliable posterior error estimates, i.e., estimates of the errors

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Theory and Practice of Data Assimilation in Ocean Modeling**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,College of Oceanic and Atmospheric Sciences,Corvallis,OR,97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

in the final product, are an essential part of any data assimilation system. We plan to use real and simulated data in a few specific cases to study the impact of prior error estimates on the analysis and on the posterior error estimates.

Work is proceeding toward a theoretical basis for the next generation of data assimilation methods, in which randomness and nonlinearity must be taken into account. To this end, we are applying tools from stochastic differential equations and from dynamical systems theory. Since our model systems are characterized by high dimensional state spaces, Monte Carlo methods must be used to study the behavior of the stochastic systems.

WORK COMPLETED

We have characterized the qualitative behavior of our simple barotropic quasigeostrophic model. This is the most complex model we know of for which such structure has been described at this level of detail. We have taken the first steps toward meaningful visualization of high dimensional stochastic systems.

RESULTS

We have found multiple stable limit cycles for a single set of parameter values in our quasigeostrophic model. This model is very similar to the one proposed by Charney and deVore (1979) to explain blocking events in the mid-latitude atmosphere in terms of multiple stable steady states of a nonlinear model. The multiplicity of steady solutions they found did not persist when the resolution was increased, but multiple stable limit cycles have been observed in parameter ranges where multiple stable steady states do not exist at high resolution. This provides an example of the existence of multiple stable regimes in models derived from geophysical fluid dynamics. We have also characterized more complex attracting sets such as invariant tori.

We have implemented a stochastic form of our model, and have demonstrated transitions from one stable regime to another. The upper panel of figure 1 shows a transition of our 44 dimensional system, from one stable regime to another, projected into three dimensions. The stable limit cycles are shown to emphasize the transition. Sampling of our spectral model in physical space shows that the transition appears conspicuously in the time series of observations of the streamfunction at several fixed points. Such transitions have been observed in the past only in highly simplified schematic systems; see, e.g., Miller et al., (1994). Application of advanced least squares techniques such as the extended Kalman filter and the ensemble Kalman filter (see, e.g., Evensen, 1994) shows that they fail in this case. An example is shown in figure 2.

IMPACT/APPLICATIONS

Major weather centers, including the US National Center for Environmental Prediction (NCEP) and the European Center for Medium-Range Weather Forecasting (ECMWF) now use ensemble methods for operational forecast validation. Our work on Monte Carlo methods should provide enhanced capability for validation of forecasts of the ocean and atmosphere, in addition to application to data assimilation.

TRANSITIONS

Results of earlier work in this project on data assimilation can now be considered as research and development tools, as opposed to subjects of research in and of themselves. A reduced state space form of the Kalman filter was used in to perform Observing System Simulation Experiments (OSSE) to help guide and assess the effectiveness of variaous configurations of a tropical Atlantic moored array. In the past, most OSSEs based on data assimilation were performed after the experimental design had been implemented and the instruments were in the water. While planning for other observational programs

has been guided by model studies, and some work in data assimilation has been specifically directed toward the principles of array design, this is the most advanced data assimilation study used to date for design of a real array.

RELATED PROJECTS

1. Work has begun on development of a data assimilation system to be used with surface velocity data from coastal radar. This project is in collaboration with Professor John Allen and Dr. Richard Scott.

2. Techniques similar to the ones under investigation here are being applied to the study of the tropical ocean and atmosphere. The goal is application to the prediction models of the ENSO cycle.

REFERENCES

Charney, J. G. and J. G. DeVore, 1979: Multiple flow equilibria in the atmosphere and blocking. J. Atmos. Sci., 36, 1205-1216.

Evensen, G., 1994: Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte-Carlo methods to forecast error statistics. J. Geophys. Res., 99, 10143-10162.

Miller, R.N., M. Ghil and F. Gauthiez. Advanced Data Assimilation in Strongly Nonlinear Dynamical Systems. J. Atmos. Sci., 51, 1037-1056, 1994.

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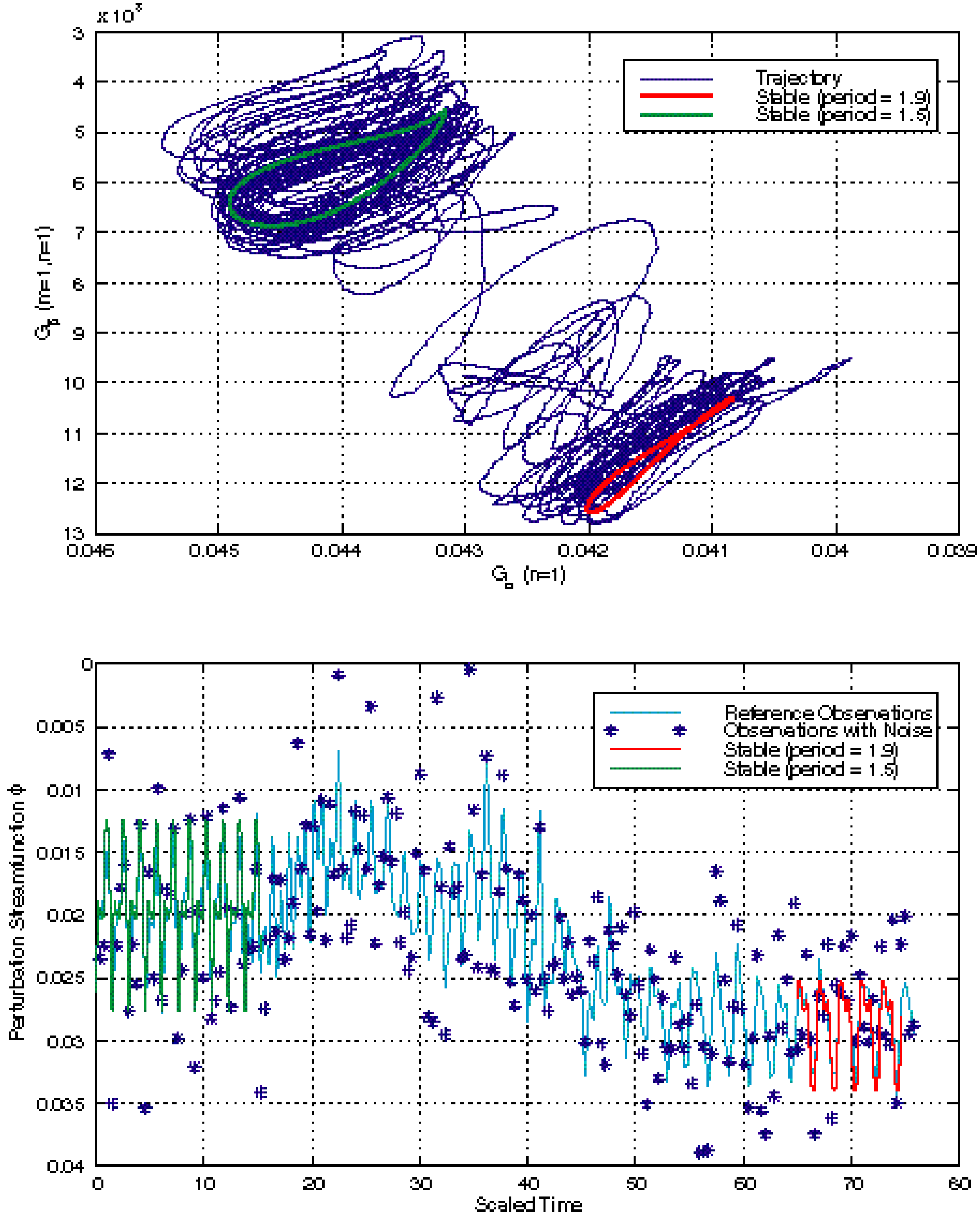

Figure 1. Trajectory of the stochastic system, showing transition between the two stable regimes. Top: the trajectory projected into the subspace of amplitudes of the waves with lowest wavenumber. The stable limit cycles are shown to emphasize the transition. Bottom: streamfunction observed at a single point in physical space, with noisy observations and stable limit cycles shown for comparison.

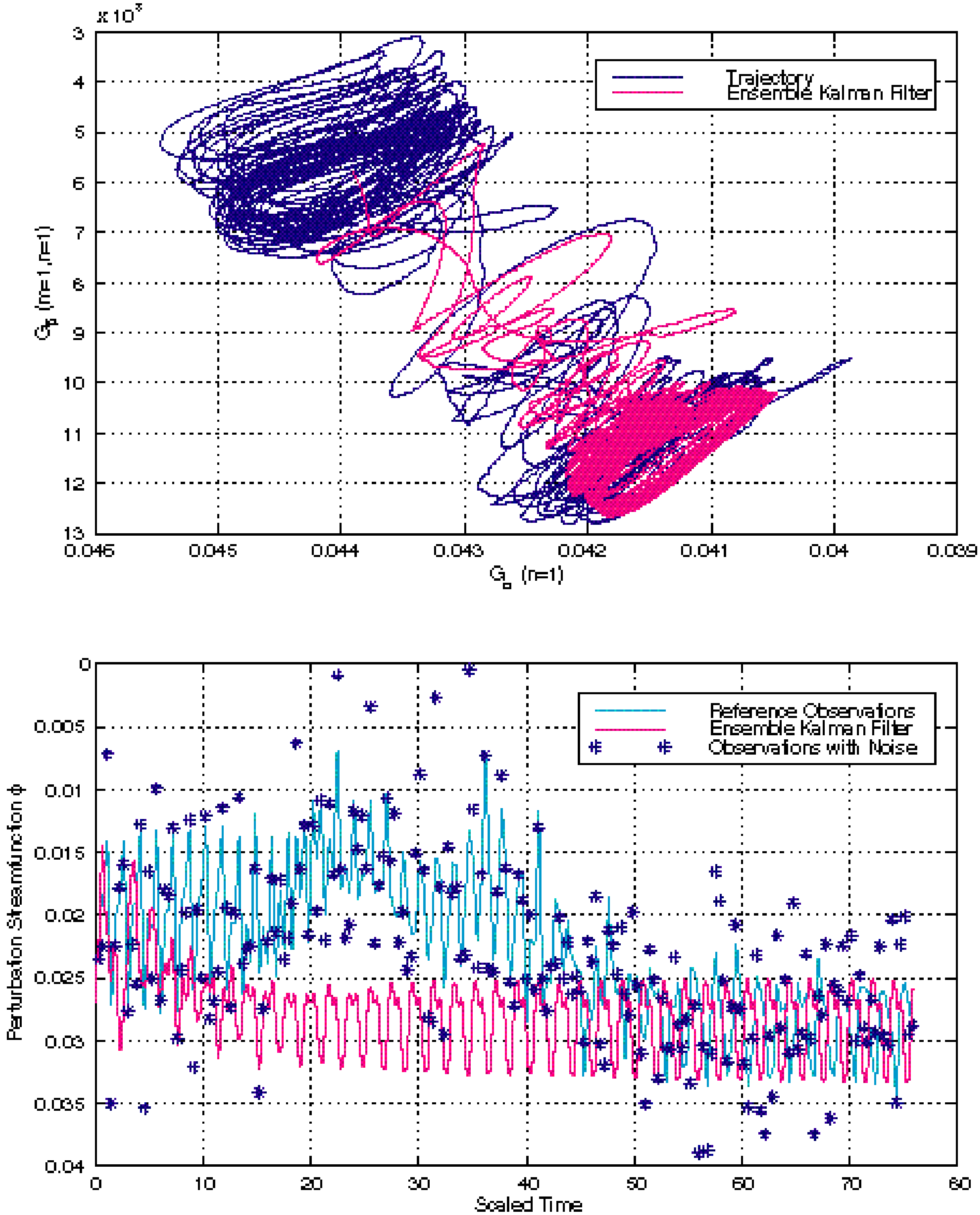

Figure 2: Failure of the ensemble Kalman filter. Top: Reference trajectory (blue) and output of ensemble filter (magenta) shown in phase space similar to Figure 1 Bottom: similar to top, but for the physical measurement.